Sources of wind-blown dust in Northern China: towards developing an Asian Dust Databank

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Introduction

Wind-blown mineral dust causes diverse effects on human health, oceanic ecosystem, regional environment and climate (Gao et al., 2001; Sokolik et al., 2001). The magnitude of the dust impacts depends on the amount and physical and chemical properties of atmospheric dust, which are largely controlled by the dust source. Currently, the strength of major dust sources is poorly constrained mainly due to both the complexity of dust emission mechanisms and a lack of data.

Northern China is the second world's largest source of atmospheric dust, but less studied than the Saharan and US sources. The main objective of our ongoing work is to set up a framework for comprehensive characterization of dust sources and atmospheric dust properties in Asia by combining data and modeling. In particular, we have been compiling the Asian Dust Databank which currently comprises the geographical, pedological and climatological data for Northern China (Xuan and Sokolik, 2001). The data were used to quantify the source strength in terms of emission rates, as well as to characterize dust sources in Northern China. We identified three broad types of dust sources: Type1. Deserts in dry-agricultural areas, Type2. Gobi-deserts and deserts located on the plateaus, and Type3. Deserts and gobi-deserts located in topographical lows. Types 1, 2 and 3 sources contribute to the annual mean PM_{10} emission 1%, 36% and 63%, respectively. Although the maximum of dust emission occurs in spring, each source type has a distinct seasonal cycle. We suggest that extreme aridity and strong winds are the main factors controlling the dust emission in Northern China. Here we present a brief description of the Asian Dust Databank and three types of dust sources in Northern China.

Developing the Asian Dust Databank

The Asian Dust Databank has been designed to record diverse classes of the data related to dust production, transport, and effects in the atmosphere. The Databank is subdivided into three major data categories such as (1) Climate data, (2) Soil and dust emission data, and (3) Data for Case Studies: Meteorology and dust events of Spring 2001. Currently, we are compiling a new category consisting of geochemical data to better characterize the chemical and mineralogical properties of surface soils and wind-blown dust.

The first category consists of the climate data: monthly means for the 1961-1990 time period from 647 surface weather stations and 124 aerological stations in China. The data include all routine surface weather observations and aerological sounding data such as air pressure,

geopotential height, air temperature, dew-point deficit, relative humidity, wind direction, wind speed, precipitation, visibility, cloud, and snow cover, etc.

The second category consists of soil data (soil texture, composition, vegetation cover, land use, etc.) and dust emission rates of PM_{10}, PM_{30} and PM_{50}, i.e., the dust particles smaller than 10, 30 and 50 micron in diameter, respectively. Dust emission rates were calculated on the climatic (30-year mean) scale at a spatial resolution of about 2.5° x 2.5° degrees (92 grid points across Northern China) (Xuan, 1999, Xuan et al., 2000, Xuan and Sokolik, 2001). The calculations were based on modified U.S. EPA formulas. To illustrate, Figure 1 shows the distribution of PM_{10} emission rates in Northern China (Xuan and Sokolik, 2001). One can point out a strong east-west graduate in emission rates.

The third category of data is dedicated to case studies. Currently, we are focusing on the Spring of 2001 in the scope of the ACE-Asia field experiment. This category includes three sub-categories: (a) surface data, (b) aerological sounding data, (c) visibility data and (d) satellite imagery.

The key feature of the Asian Dust Databank is that it has been specifically designed for dust emission and transport studies. The main difference from other existing databases (such as FAO and NSCD soil databases) is that it includes not only soil properties but also meteorological and satellite data. Thus, it adds an additional, vertical dimension to the traditional GIS-type databases. This is a critical issue since dust mobilization and transport and hence the dust effects in the atmosphere are controlled by both meteorological characteristics and land surface features.

Identification and characterization of dust sources in Northern China

It is recognized that dust mobilization is a complex process controlled by various surface properties and local meteorological conditions. Thus, a combination of these factors must be considered to quantify the strength of a dust source. To guide the characterization of dust sources, we introduced an integrated set of the following factors: the frequency of dust storm occurrence, wind speed, aridity and precipitation, morphology and composition of surface soil, and dust emission rates (Xuan and Sokolik, 2001). Combining these factors, we performed comprehensive, comparative characterization of dust sources in Northern China, identifying their commonalities and specific features that affect dust emission. We also addressed the effects of human activities and land use change on dust emission in this region.

We identified and characterized three broad types of dust sources in Northern China. Figure 2 shows that these sources spread from east to west, reflecting a rapid decrease in the precipitation and the increase in aridity and emission rates. The relative contribution of Types 1, 2, and 3 sources to the annual mean dust emission is about 1%, 36% and 63%, respectively.

Type 1. Deserts in dry-agricultural areas.
Type 1 sources consist of the Hulun Buir Desert, Horqin Desert, Hunshandake Desert, Mu Us Desert, and Hobq Desert. The name "dry-agricultural" means that farming strongly depends on irrigation because of the limited rain fall (200–400 mm/yr, with 75% in the summer season). This is an arid area in which farmlands (about 6.82×10^4 km^2), dry-grasslands (58.11×10^4 km^2) and sand deserts (13.76×10^4 km^2) are alternatively distributed. There are no Gobi-deserts in this region.

Because of the cold waves from Siberia, the wind speed is rather high in the winter and spring seasons. The 30-year climatic data show that the Type 1 sources lie in the high-frequency duststorm region. Our calculations predict annual mean emission of PM_{10}, PM_{30} and PM_{50} in Type 1 sources of 0.1, 0.2 and 0.5 million tons, respectively.

Type 2. Gobi-deserts and deserts located on plain plateaus.

This type of sources mainly consists of the Central Gobi-desert, Ulan Buh Desert, Tengger Desert, Badain Jaran Desert and the gobi-deserts in the Hexi Corridor. The Central Gobi-desert is located in the west part of the Inner-Mongolia Plateau, while the other three deserts are located on the Alxa Plateau. The existence of gobi-deserts suggests that it is an extremely dry area. Precipitation is about 50–200 mm/yr and the vegetation coverage is less than 10% on average.

Our calculation shows that annual mean emissions of PM_{10}, PM_{30} and PM_{50} in Type 2 sources are 2.9, 6.9 and 13.2 million tons, respectively. The large part of the Central Gobi-desert extends into the Republic of Mongolia. Because of various similarities between Chinese and Mongolian parts, the latter can be considered as the Type 2 source. Assuming the same emission rates for Mongolian and Chinese parts of the Central Gobi-desert, we estimated that about 4.7 million tons of PM_{10} dust might be emitted annually into the atmosphere from the Mongolian part, while the Chinese part emits about 2.7 million tons.

Type 3. Deserts and gobi-deserts located in topographical lows.

This source type mainly comprises the Taklimakan Desert, Gurbantunggut Desert, Kumtag Desert, Hashun Gobi-desert, Turpan-Hami Basin (gobi-desert) and Tsaidam Basin (gobi-desert and playa). All these deserts and gobi-deserts are located in the basins or on flanks of high mountains. The Taklimakan Desert, being surrounded by high mountains and located far from the oceans, receives extremely low annual precipitation (0-20 mm/yr). Almost the entire Taklimakan is devoid of plant cover. As a result, the Taklimakan Desert is a prodigious dust source, being a main supplier of wind-blown dust in East Asia. Overall for Type 3 sources, our calculations give annual mean emissions of PM_{10}, PM_{30} and PM_{50} dust of 5.4, 17.6 and 28.9 million tons, respectively, The relative contributions of these sources to the total dust PM_{10}, PM_{30} and PM_{50} in Northern China is 63%, 71% and 68%, respectively.

Summary

We have been compiling the Asian Dust Databank which currently comprises the geographical, pedological and climatological data for Northern China. These data enabled us to perform comprehensive characterization of dust sources and to estimate their strengths on the climatic (30-year mean) scale. Our main findings are the following:

i). The Taklimakan Desert is a main source of atmospheric dust in Northern China. The next important sources are the Central Gobi-desert and the deserts on the Alxa Plateau - the Ulan Buh Desert, Tengger Desert and Badain Jaran Desert. The Loess Plateau appears to be a weak dust source.

ii). We identified three broad types of dust sources in Northern China. In addition to Types 1, 2, and 3, the Hexi Corridor and Tsaidam Basin are two unique dust sources we have identified. The former has characters of the all three types and is currently included in Type 2, and the latter is currently included in Type 3, having characteristics of alpine deserts. Relative

contributions of Types 1, 2, and 3 sources to the annul mean dust emission is about 1%, 36% and 63%, respectively.

iii). Analyses of both the spatial distribution and seasonal variation of dust emission rates demonstrate that extreme aridity and strong winds are the main factors controlling dust emission in Northern China.

iv). Human activities, mainly exhaustive farming, over-grazing and improper use of limited water resources in arid and semi-arid lands, have seriously damaged the natural environment in Northern China, causing the expansion of dust sources. In particular, Type 1 sources seem to be more vulnerable due to rapid population growth in this region.

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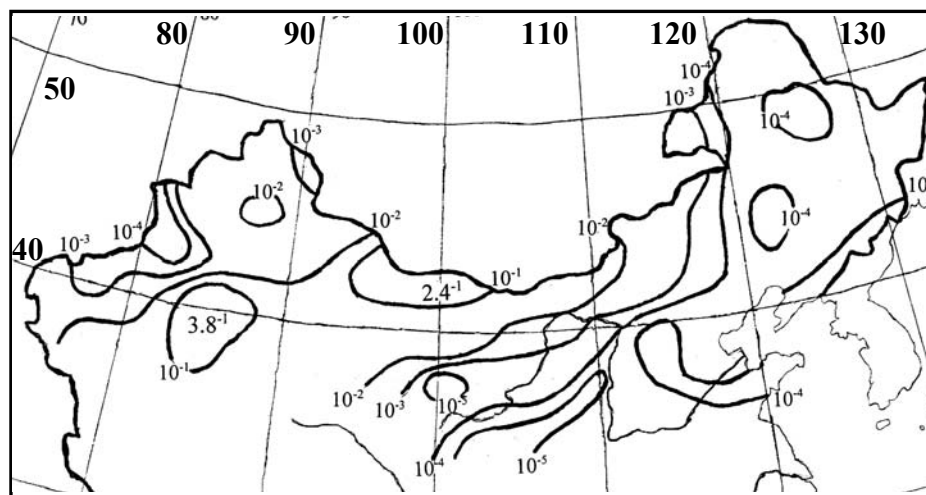
Figure 1. Annual mean PM$_{10}$ dust emission rates (t ha^{-1} yr).
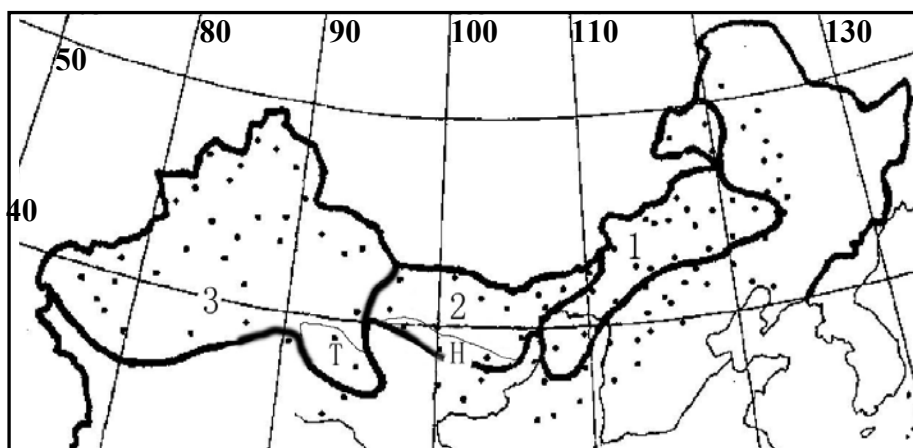

Figure 2. Three types of dust sources in Northern China. The dots show the main weather stations; H: Hexi Corridor; T: Tsaidam Basin.